

# Stitching a MODIS-VIIRS time series of aerosol properties using the **Dark Target** algorithm: Circa 2016

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Lorraine Remer (UMBC/JCET), Robert Holz (SSEC/UWiscnsin)

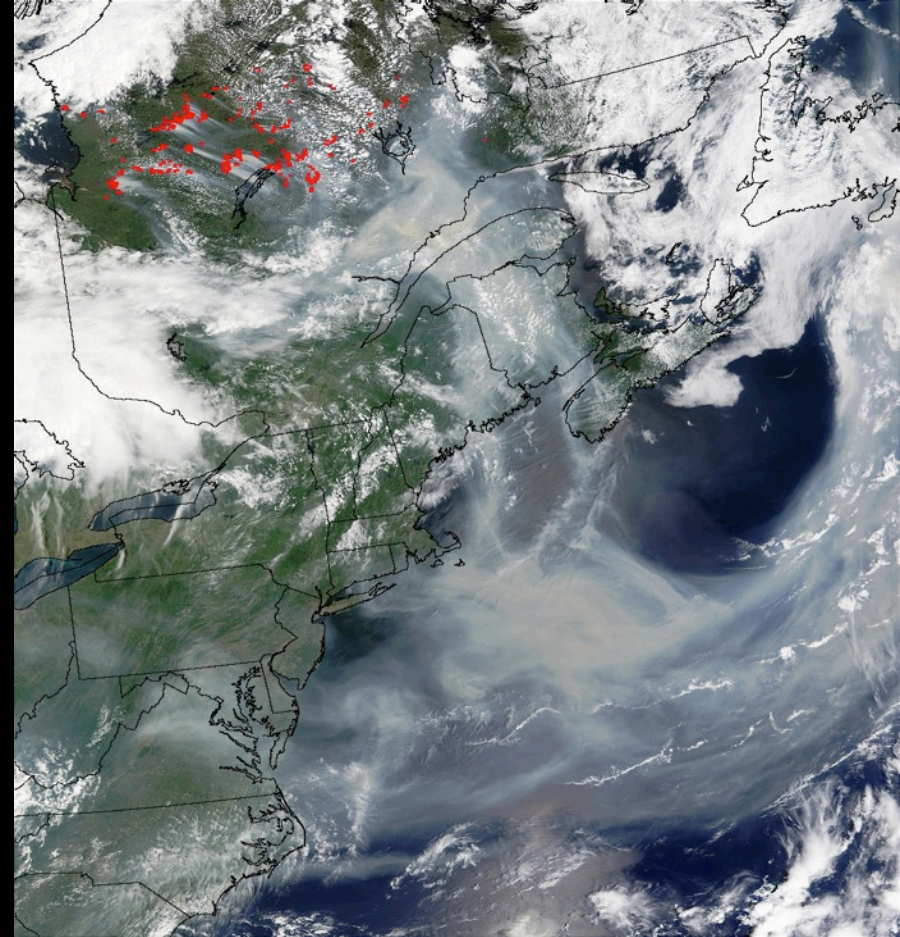
\* New people in 2016.

And many, many, many others

CERES meeting; April 2016 @ NASA LaRC

# Aerosol from space

- Aerosol optical depth (AOD or  $\tau$ )
- “Essential Climate Variable” (ECV)
  - Requires accuracy  $< \pm 0.02$
  - Measured over multi-decades
- Yet, mostly a “regional” problem.
- Required uncertainty (per pixel) =  $< 15\%$ .
- Desire: separation of aerosol types and effects



**Smoke** transported over Eastern Canada/USA (8 July 2002)

# Outline

1. “Dark-target” (DT) remote sensing on MODIS
2. Terra vs Aqua (and calibration and trends)
3. DT applied to VIIRS (using Wisconsin IFF)
4. Challenges of MODIS→VIIRS continuity
5. Advancing the DT algorithm
6. Summary



# MODIS on Terra and Aqua

## Moderate resolution Imaging Spectroradiometer

**Orbit:** 705 km, sun-synchronous, over same point every 16 days

Equator crossing: 10:30 (**Terra**, since 2000), 13:30 (**Aqua**, since 2002)

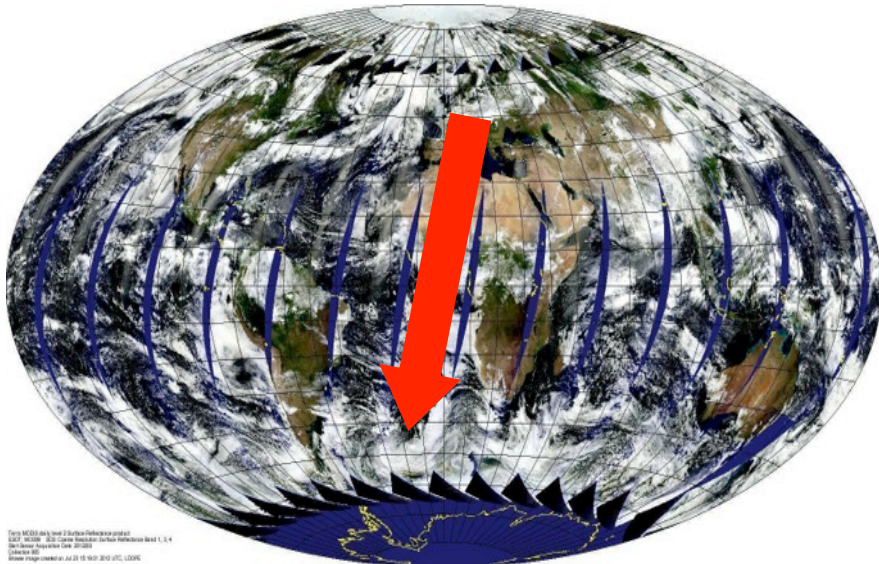
**Swath:** 2330 km (55° cross track)

**Spectral Range:** 0.4-14.4 $\mu$ m (36 bands). 19 in solar spectrum (< 4.0  $\mu$ m)

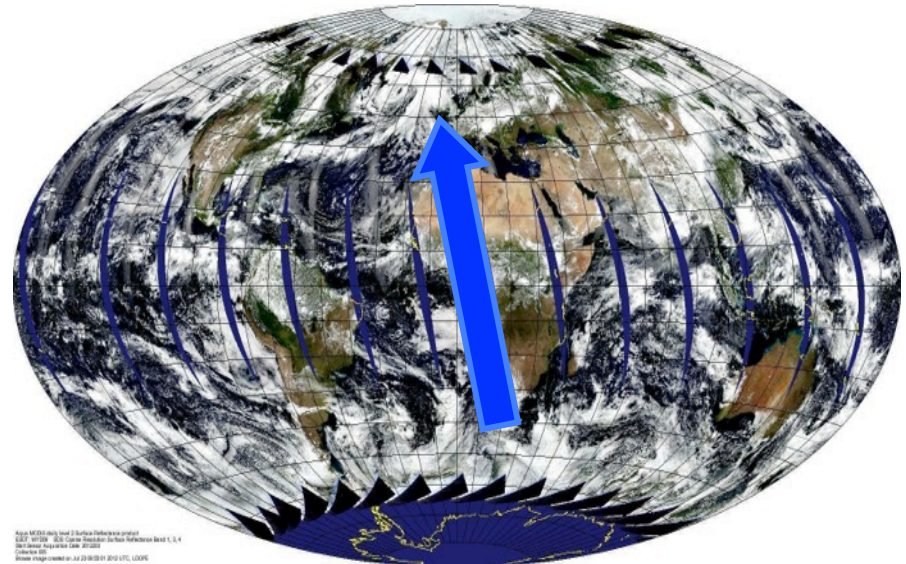
**Spatial Resolution:** 250m (2 bands) 500m (5 bands) 1000m (29 bands)

**Calibration:** On-board and continuously updated

Terra (10:30, Descending)



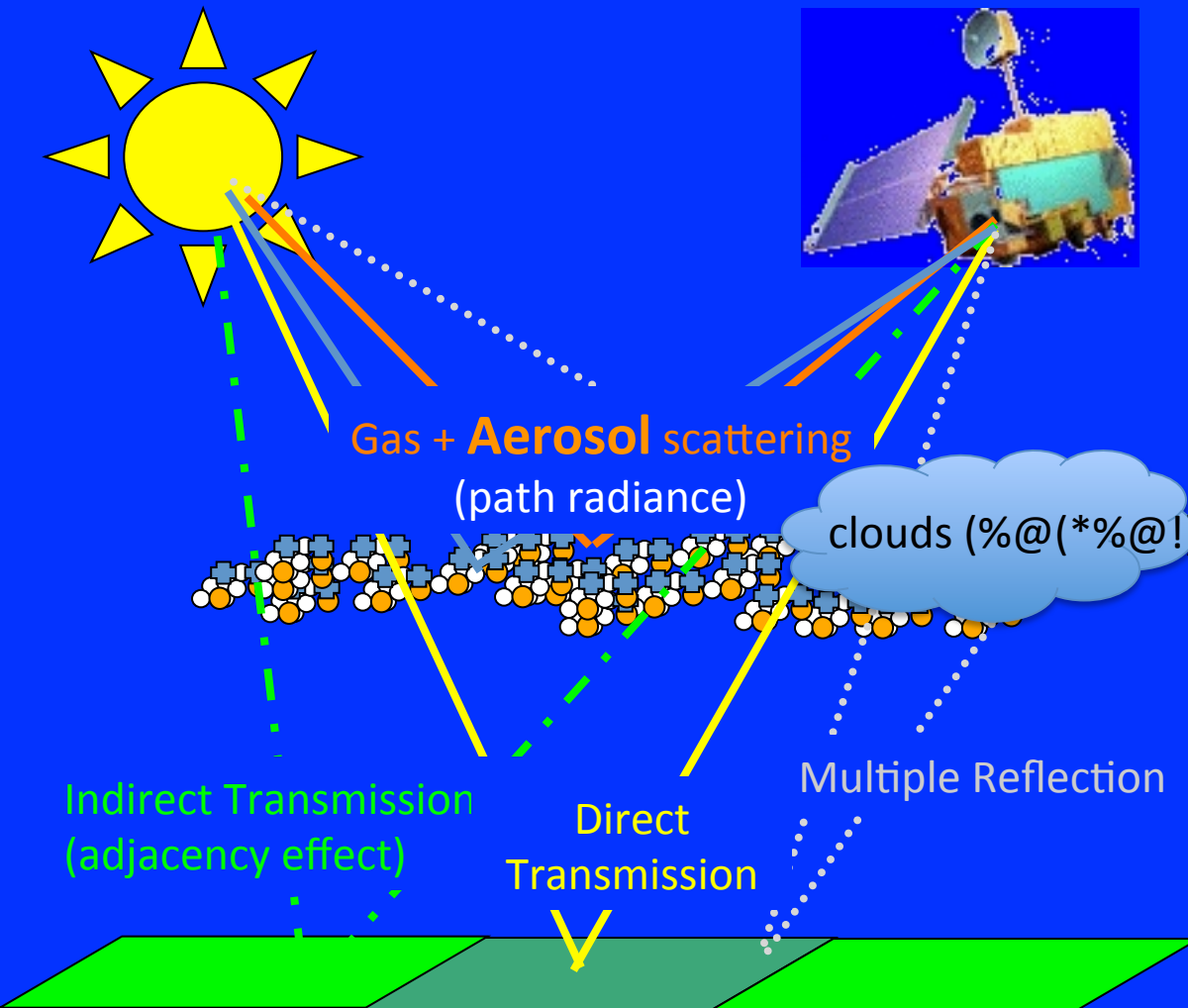
Aqua (13:30, Ascending)



Twin MODIS instruments – Two views per day!



# Complicated TOA Signal



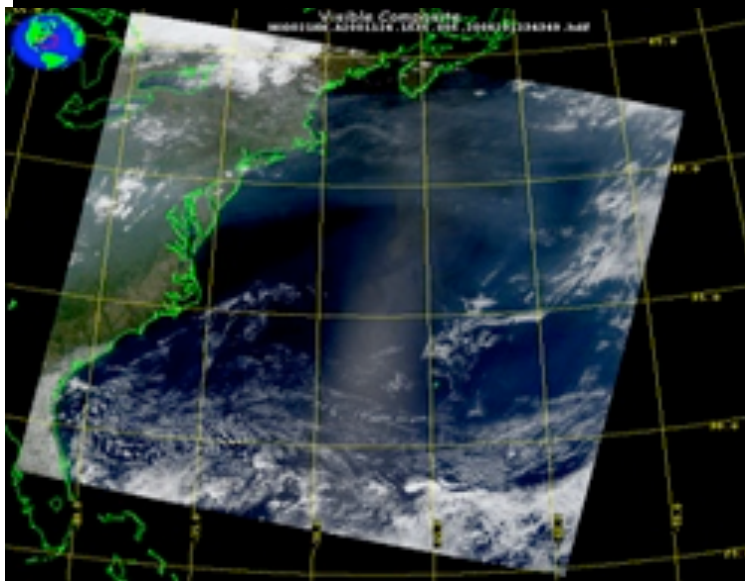
Contributions from:

- Gas absorption ( $\text{O}_3$ ,  $\text{CO}_2$ , etc)
- $\text{H}_2\text{O}$  absorption
- Rayleigh (molecular) scattering
- Aerosol scattering and absorption
- Surface reflection
- Atmosphere / Surface interaction
- Contamination from neighboring pixels (clouds, etc)
- .. And cloud masks

# Aerosol retrieval from MODIS

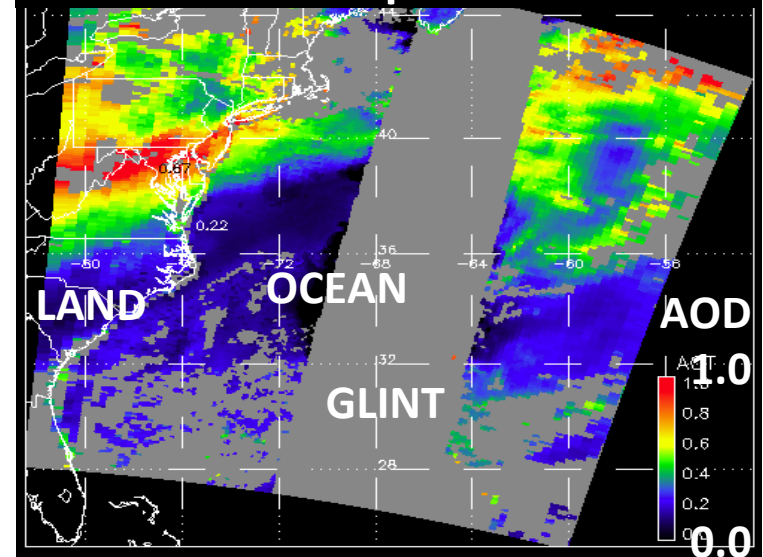
What MODIS observes

May 4, 2001; 13:25 UTC  
Level 1 “reflectance”



Attributed to aerosol (AOD)

May 4, 2001; 13:25 UTC  
Level 2 “product”



There are many different “algorithms” to retrieve aerosol from MODIS  
Ours is **Dark Target (DT)**; “Established 1997” by Kaufman, Tanré, Remer, etc)

**Separate algorithms: Ocean and Land**

**Both are multi-channel inversions**

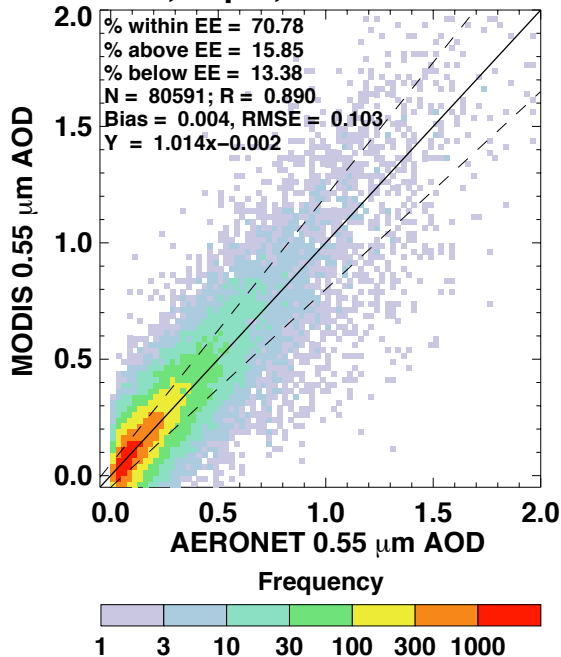
**Products = AOD at 0.55  $\mu\text{m}$ , spectral AOD, diagnostics**

# MODIS Collection 6 (10 km product): “Validated since 2014”

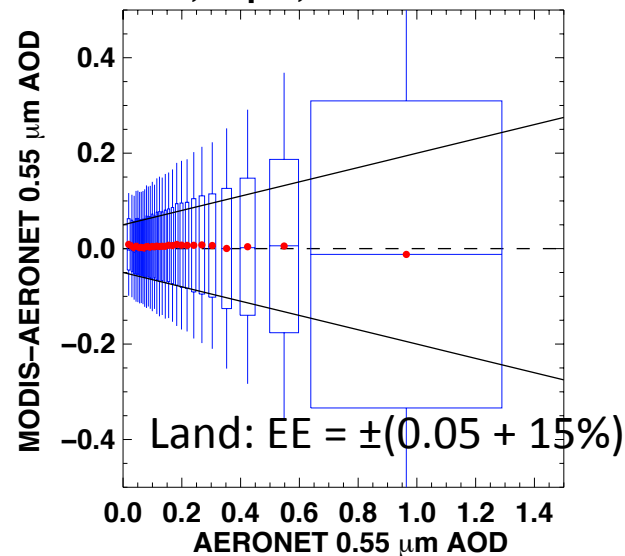
All assumptions related to assumed aerosol properties, surface reflectance, lookup tables, and cloud masks were updated for C6

Collection 6 “Webinars”: <http://aerocenter.gsfc.nasa.gov/ext/registration/>  
“dark-target” website: <http://darktarget.gsfc.nasa.gov>  
MODIS product website: <http://modis-atmos.gsfc.nasa.gov>

C6 Land, Aqua, Mar 2003–Feb 2013



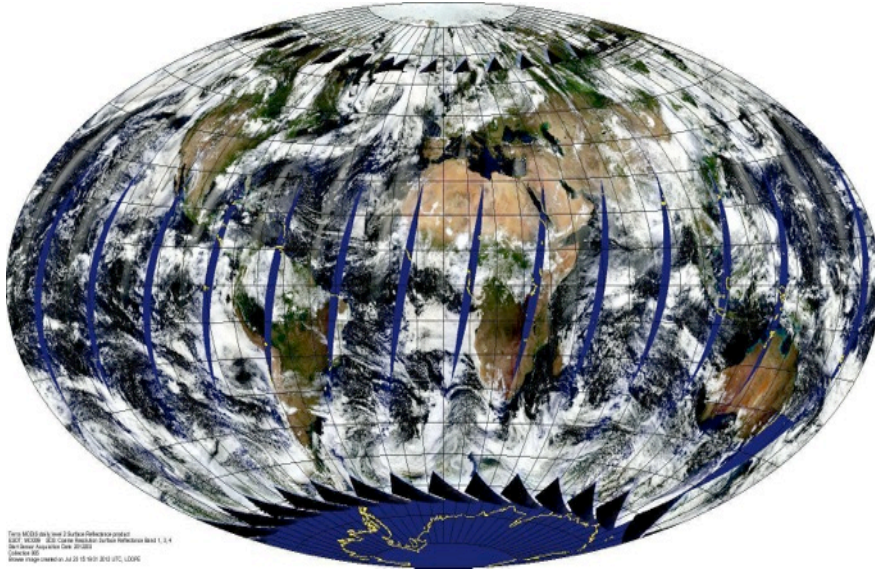
C6 Land, Aqua, Mar 2003–Feb 2013



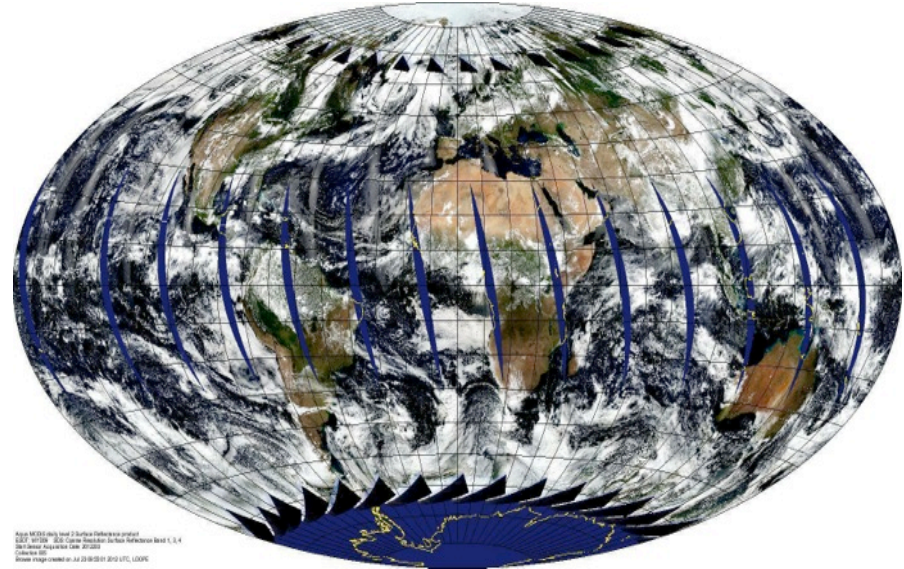


# Two validated MODIS time series: Do they represent the same world?

Terra (since spring 2000)

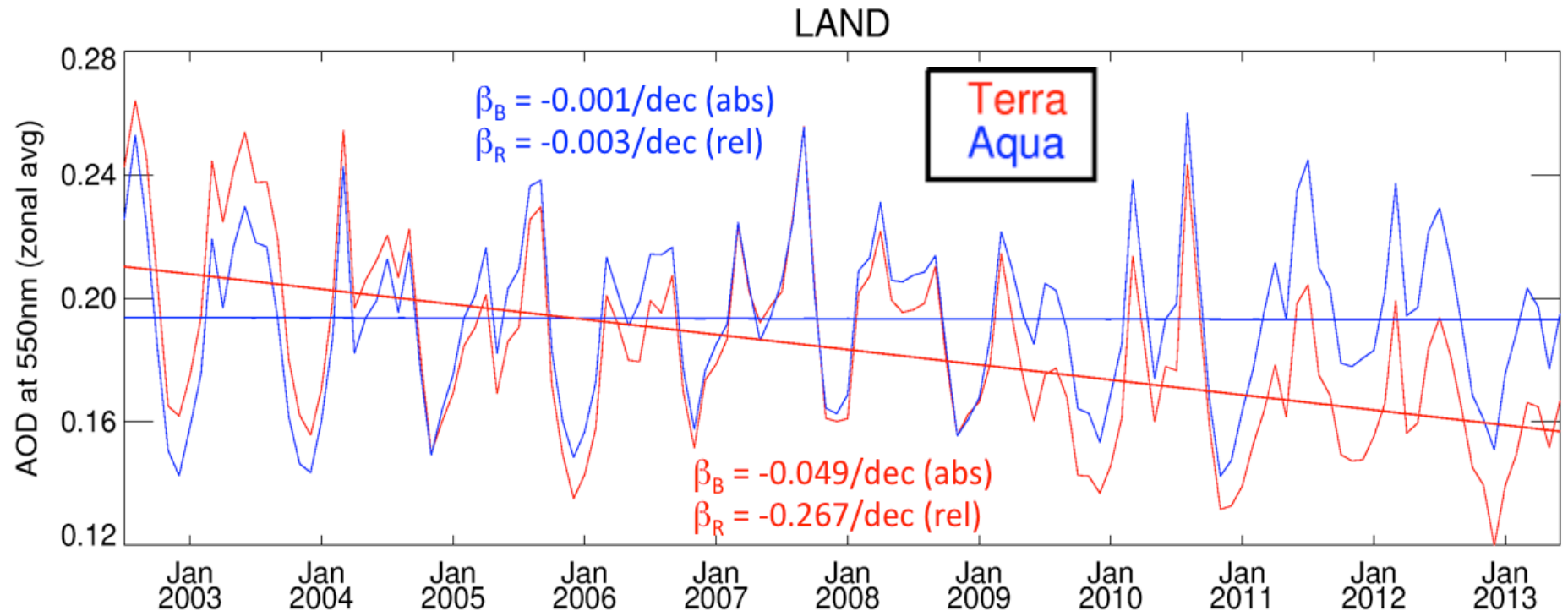


Aqua (since summer 2002)



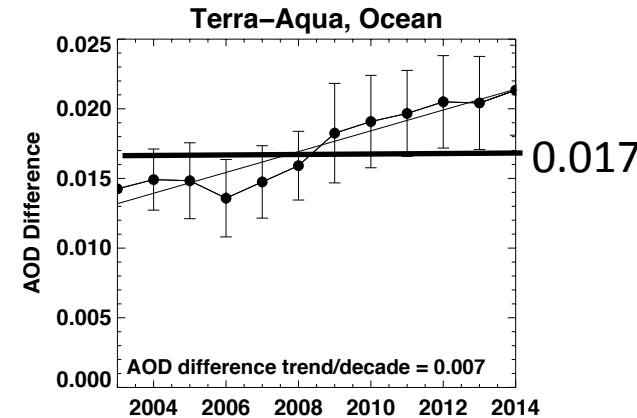
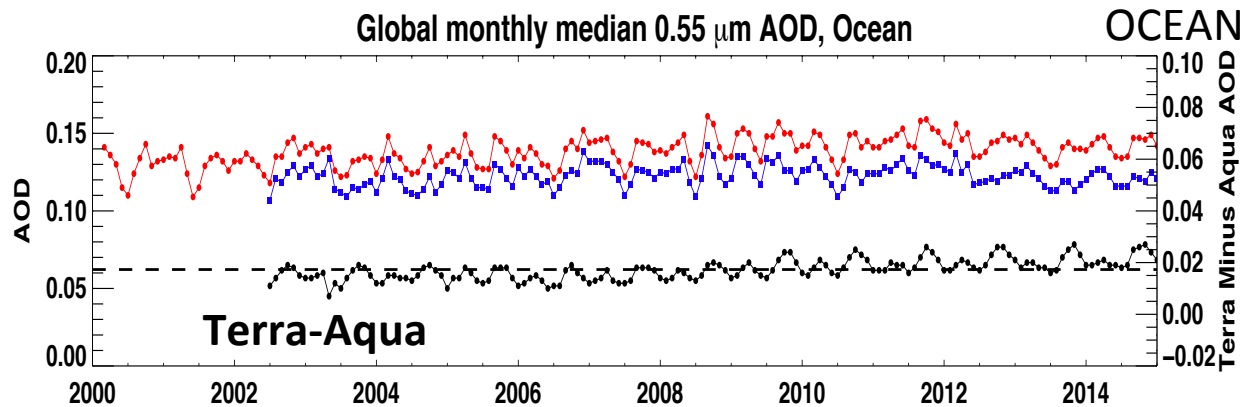
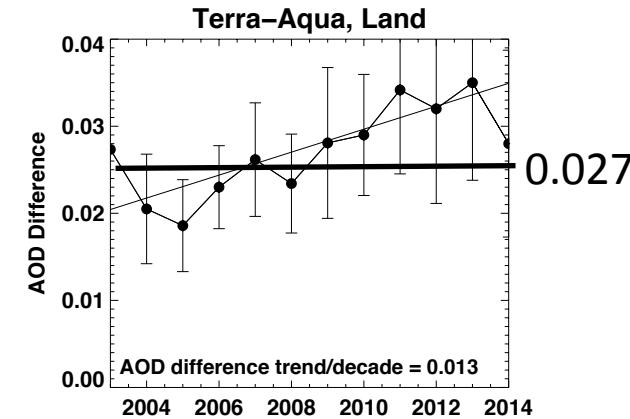
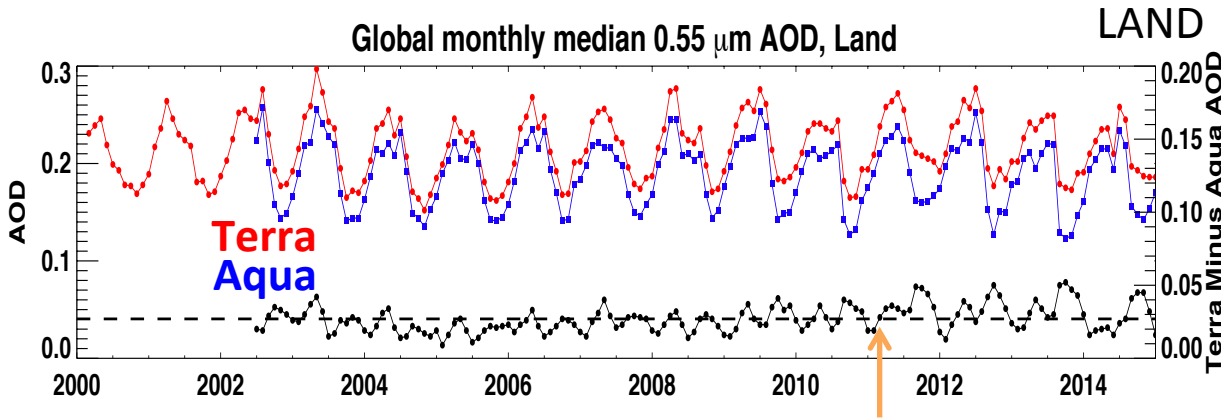
- Same instrument hardware (optical design)
- Same spatial and temporal sampling resolution
- Same calibration/processing teams
- Same aerosol retrieval algorithms
- **The two MODIS instruments are Identical twins!**  
**How do they behave?????**

# Aerosol Trends: If based on Collection 5 (C5)

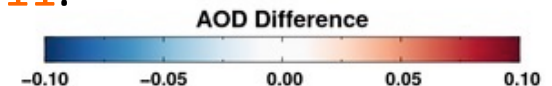
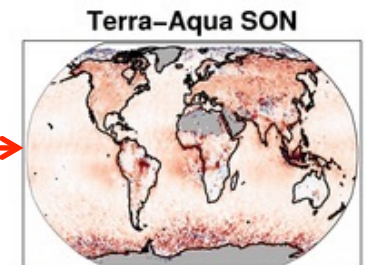


- Consider that a trend of  $\pm 0.01/\text{decade}$  is significant
- In C5, over land, **Terra decreased** ( $-0.05/\text{decade}$ ) while **Aqua was constant**
- **Terra / Aqua** divergence was similar everywhere on the globe! Not AM/PM
- → Like identical twins, the twin MODIS sensors have aged differently.
- **MCST applied a new calibration for C6, based on observing pseudo-invariant desert targets**

# C6 AOD: Terra versus Aqua



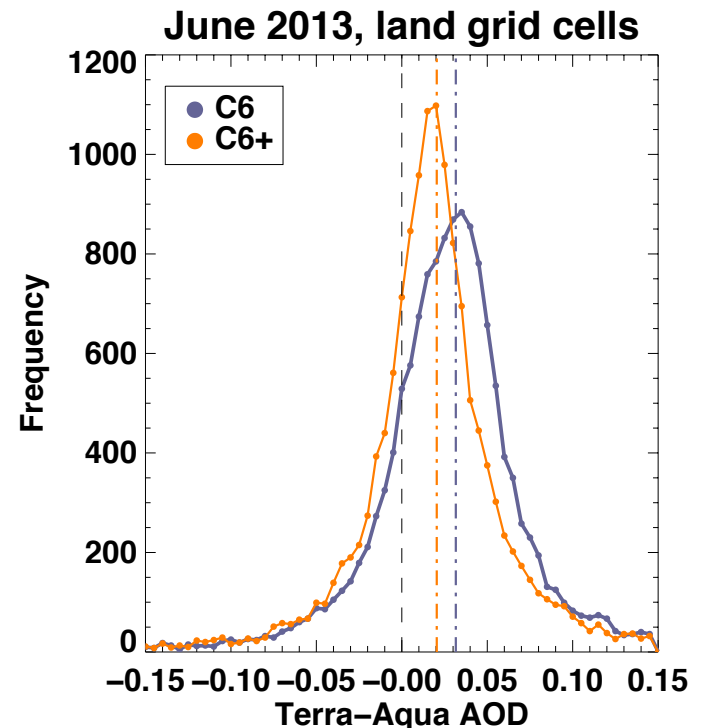
- Terra/Aqua divergence “mostly” removed for C6
- Terra AOD high by 0.027 land/0.017 ocean (13%), **Global!**
- Residual trending (Terra-Aqua increasing by  $\sim 0.01/\text{decade}$ )
- Bigger-amplitude seasonal cycle to Terra-Aqua **after 2011**.



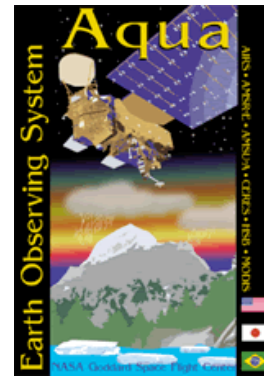


# MODIS C6 (and C6+)

- Trending issues reduced with C6 product, but:
  - Still significant offsets (13%) and
  - Still residual co-trending ( $<0.01$  / decade)
- Why? Sampling? diurnal cycles? Cloud masking?
- Calibration?
  - Test different options
  - “C6+” of Alexei Lypustin et al.,
  - Ocean vicarious corrections
  - Dave Doelling’s one
  - Me, playing on my own.
  - Etc.
- Yet, overall convergence

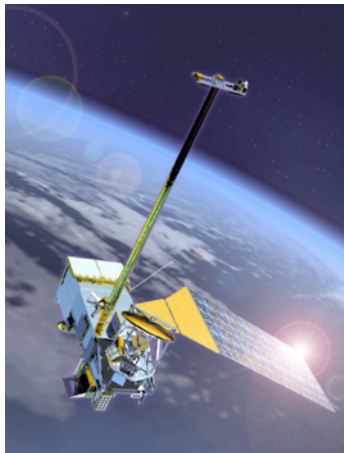


# Beyond MODIS



- Terra is driving in Virginia (16!)
- Aqua already celebrated its “Sat-mitzvah” (13).
- Both have well-exceeded their planned mission lifetimes
- Calibration continues to get trickier, and there are end-of-lifetime plans

**How do we make AOD climate data record? (20+ years of global AOD)?**



## VIIRS?

Visible-Infrared Imager Radiometer Suite  
aboard Suomi-NPP  
(and future JPSS)

# VIIRS versus MODIS

**Orbit:** 825 km (vs 705 km), sun-synchronous, over same point every 16 days

Equator crossing: 13:30 on Suomi-NPP, since 2012 (vs on Aqua since 2002)

**Swath:** 3050 km (vs 2030 km)

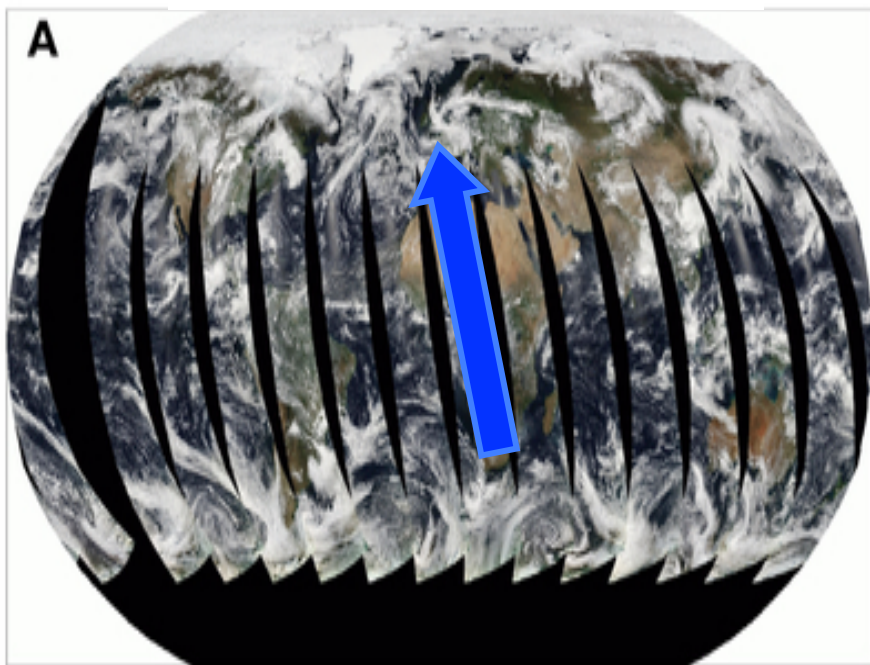
**Spectral Range:** 0.412-12.2 $\mu$ m (22 bands versus 36 bands)

**Spatial Resolution:** 375m (5 bands) 750m (17 bands): versus 250m/500m/1km

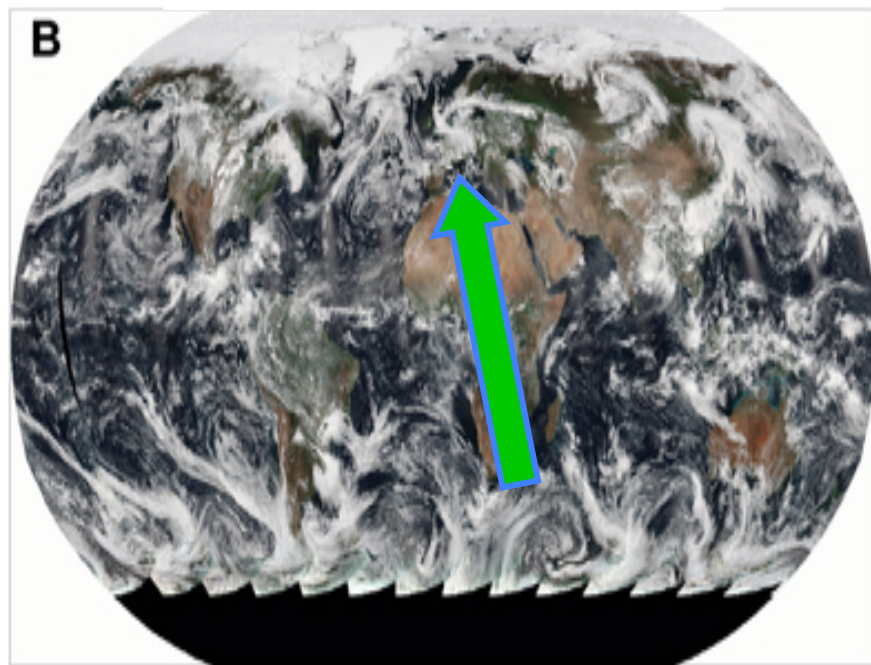
**Aerosol retrieval algorithms:** “Physics” similar, but different strategies

**Wavelength bands (nm) / DT aerosol retrieval:** 482 (466), 551 (553) 671 (645), 861 (855), 2257 (2113) → differences in Rayleigh optical depth, surface optics, gas absorption.

MODIS-Aqua – 29 May 2013

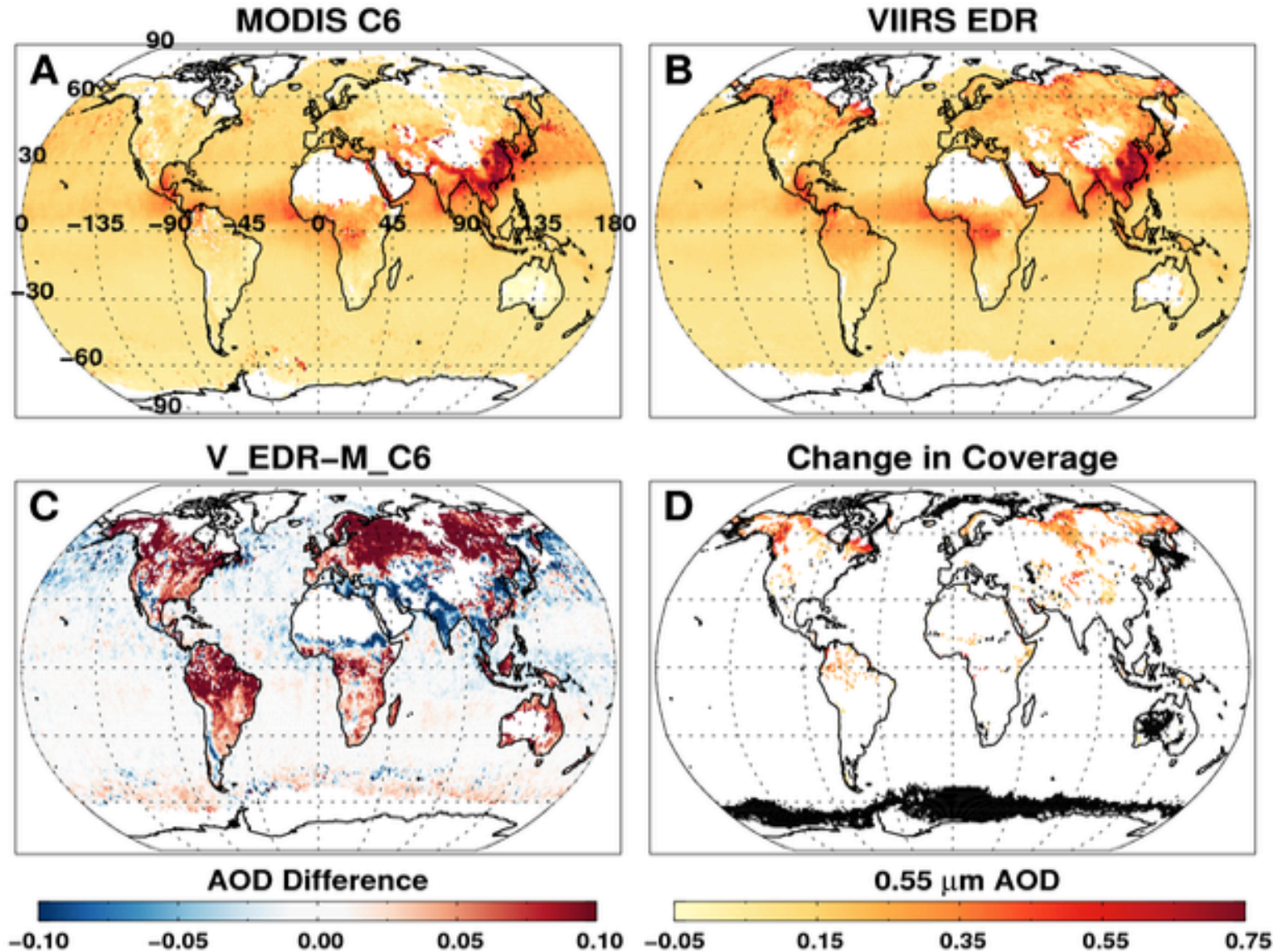


VIIRS-SNPP – 29 May 2013





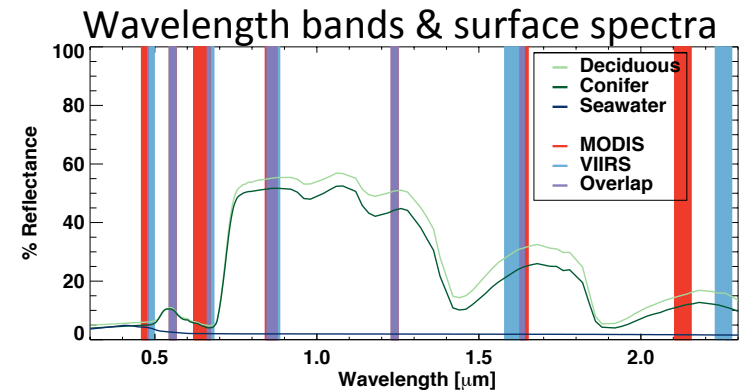
# Already a “validated” NOAA-based aerosol product



Qualitatively similar, yet quantitatively different. Especially over land  
**Cannot be used for continuation of MODIS.**

# Solution?

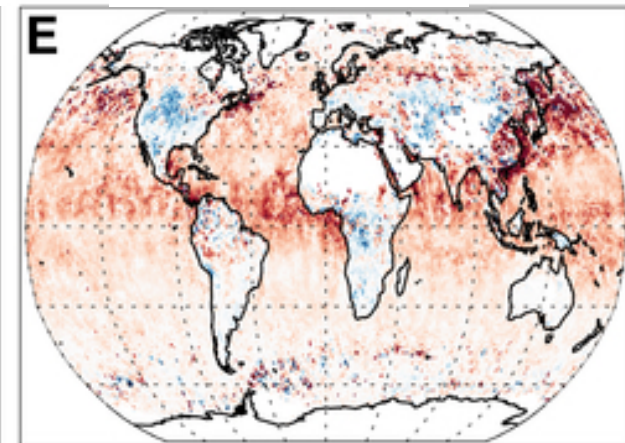
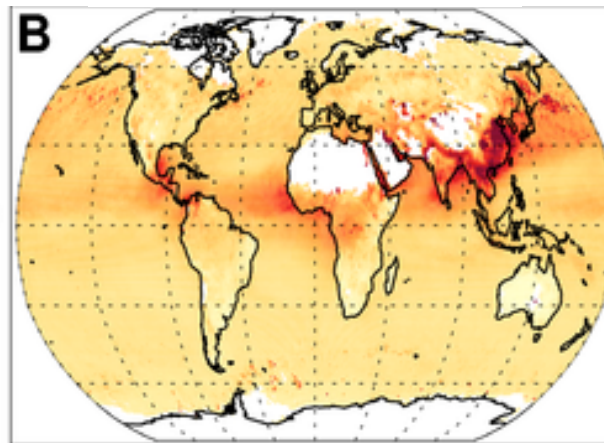
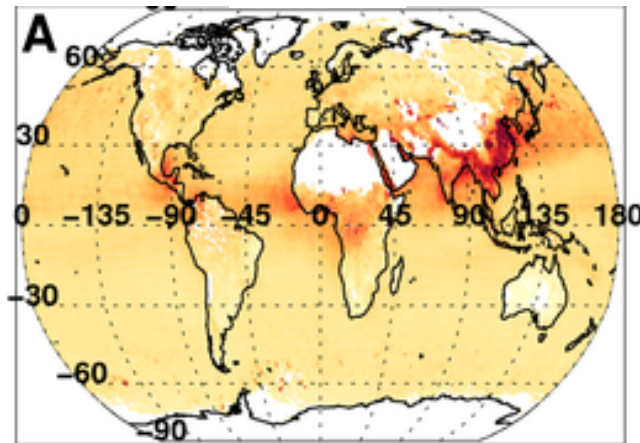
## Port the DT algorithm!



MODIS

MODIS-like on VIIRS

Difference M - V



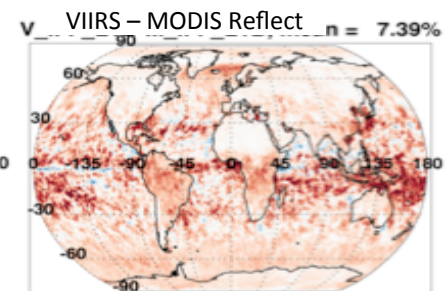
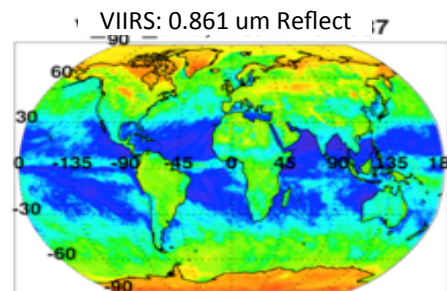
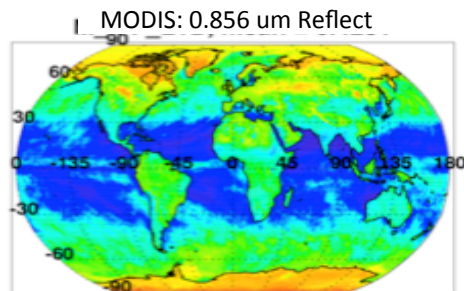
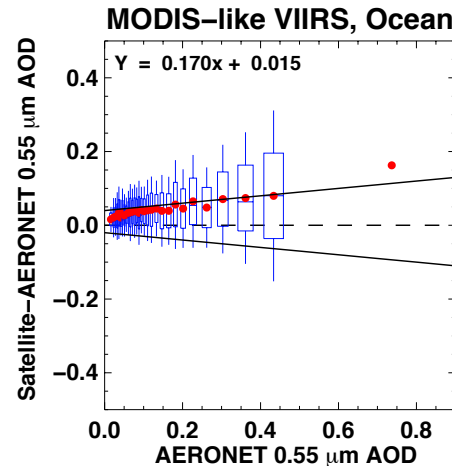
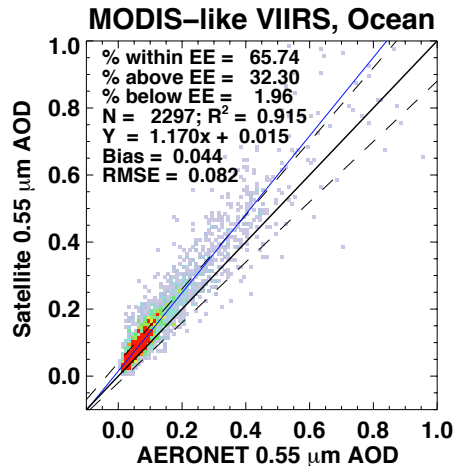
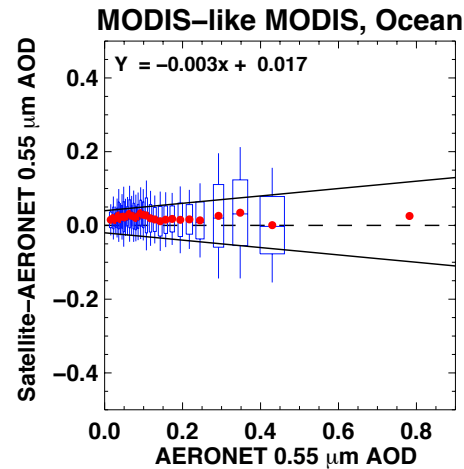
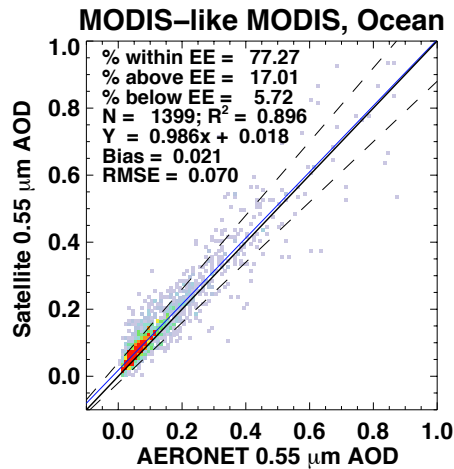
- We use Intermediate File Formats (IFF) and tools developed at the “Atmosphere-SIPS”, at the University of Wisconsin
- Results of MODIS-like on VIIRS include:
  - Reduced global AOD differences and more similar global sampling
  - Now a systematic bias over ocean (VIIRS high by 20%).
  - Déjà vu? Terra versus Aqua? (Terra high by 13%)
  - → VIIRS also needs calibration study?

# Comparing to AERONET and calibration

MODIS-like on VIIRS has great correlation but 1.17 slope!

Studies such as Uprety et al., (2013) do radiometric comparisons between VIIRS and MODIS and find that VIIRS may be 2% high in some bands.

2% high bias is sufficient to give a 1.17 slope over ocean without the adding same bias to land.



0.856 or 0.861 Reflectance

% Difference Reflectance

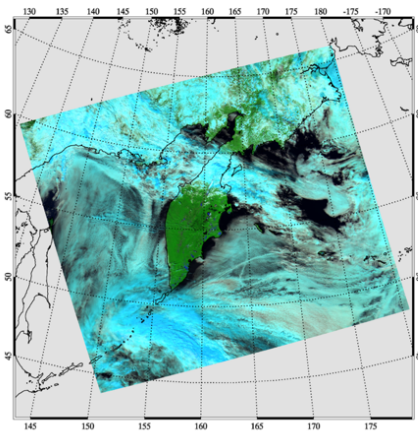




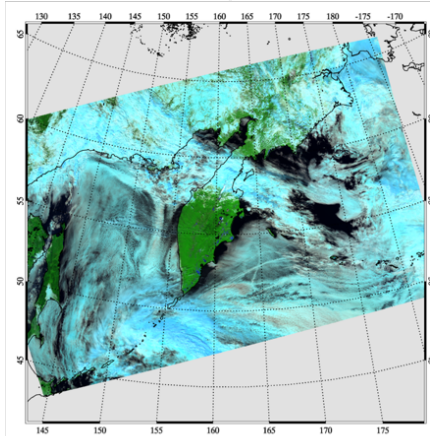
# Calibration: Match files

- Can we “prove” calibration differences? It’s hard!
  - Slight differences in orbit  $\rightarrow$  no true matches inside  $\pm 70^\circ$  latitude
  - Common geometry is very limited
  - University of Wisconsin is creating “match” files for us to look at

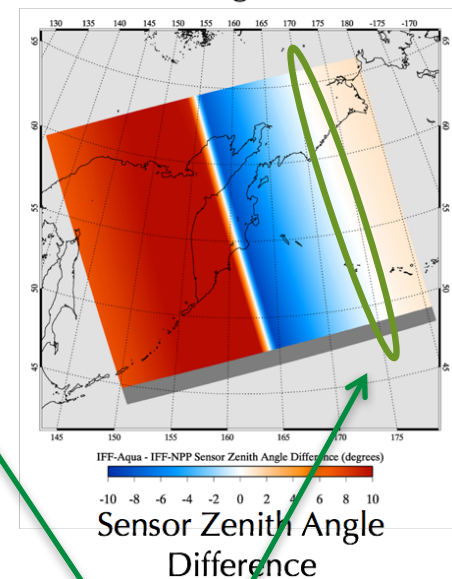
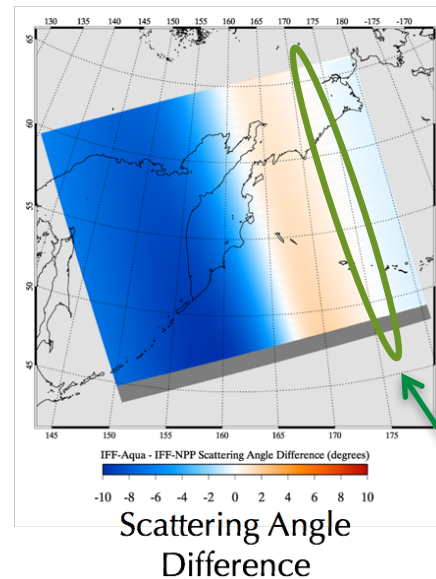
Close overpass (space and time) between Aqua and SNPP near the Kamchatka Peninsula and surrounding waters.



MODIS False Color  
(Bands 7, 2, 1)



VIIRS False Color  
(M11, M7, M5)



6 July 2014

From Steve Platnick

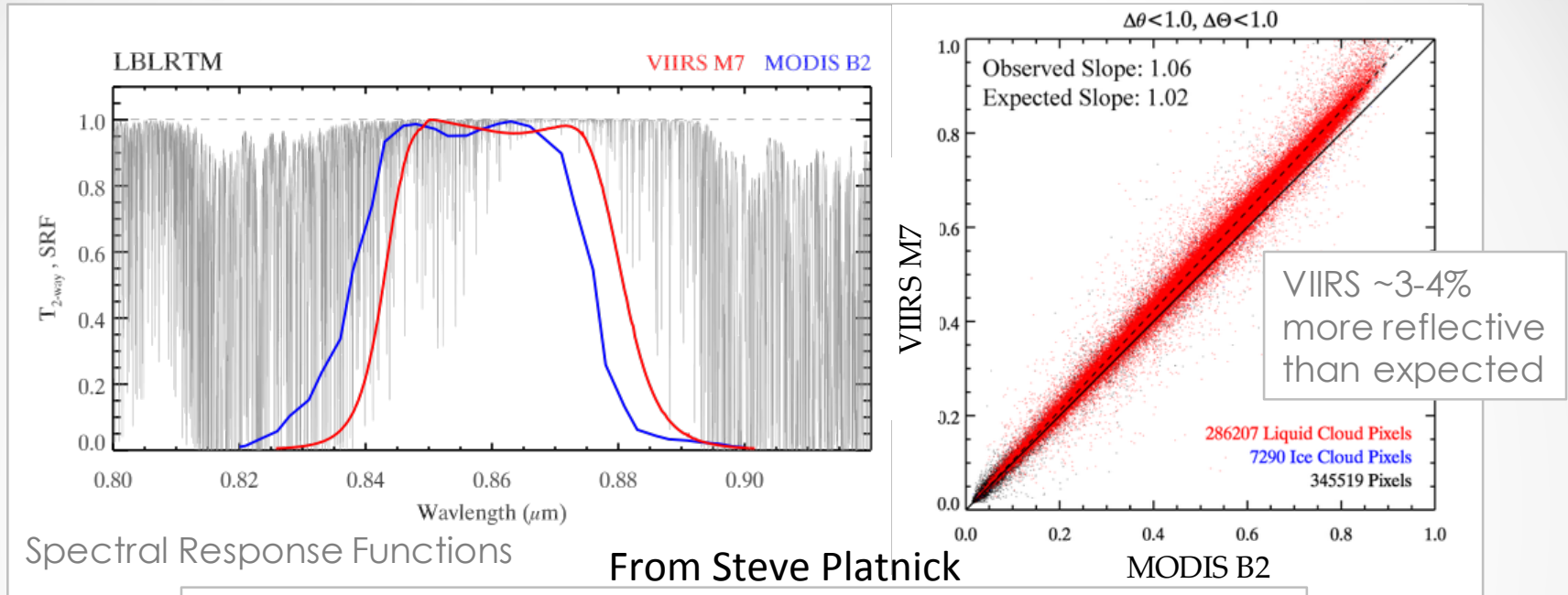
“common” geometry/angles



# Calibration: Wavelength issues

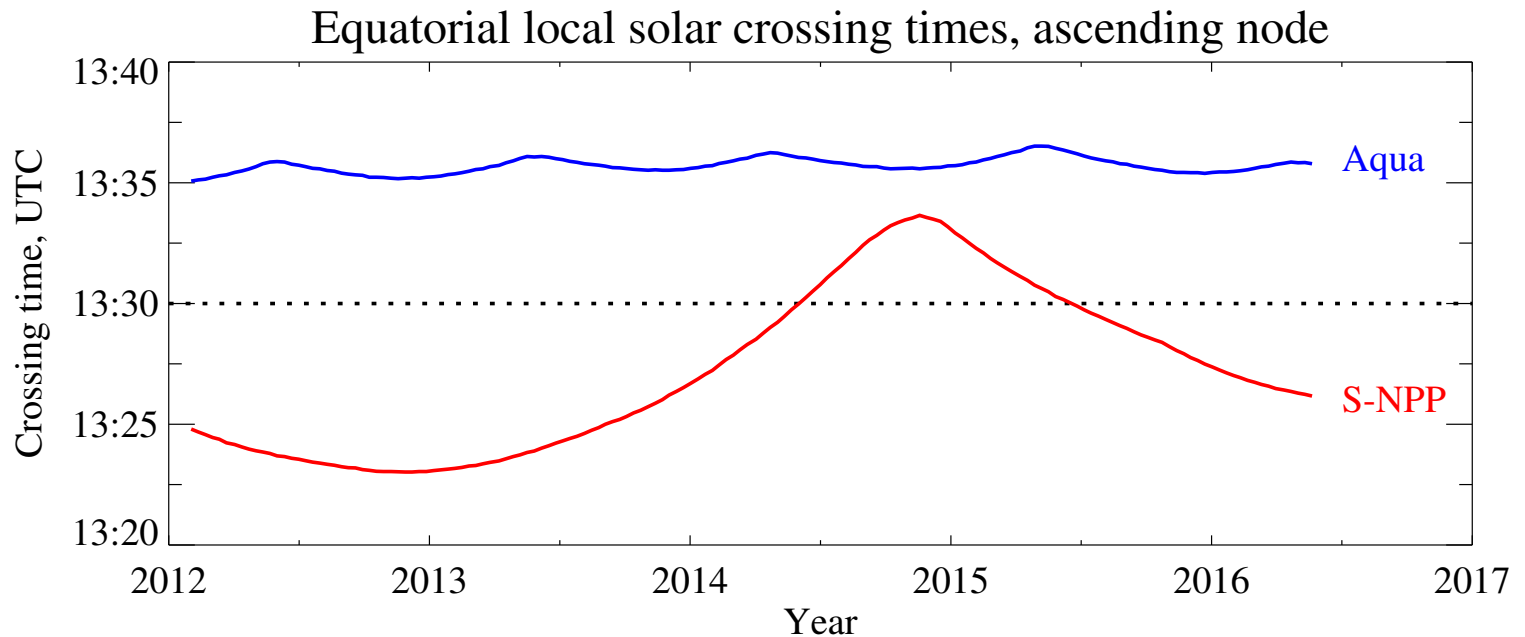
- Can we “prove” calibration differences? It’s hard!
  - Slight differences in wavelength → no true matches
  - Slight differences in Rayleigh optical depths,
  - Sometimes major differences in gas absorptions
  - With of lack of true spatial overlap, hard to find common points .

## Cloud Optical Properties: 0.86 $\mu\text{m}$ Channel Radiometry



# Calibration: Timing issues

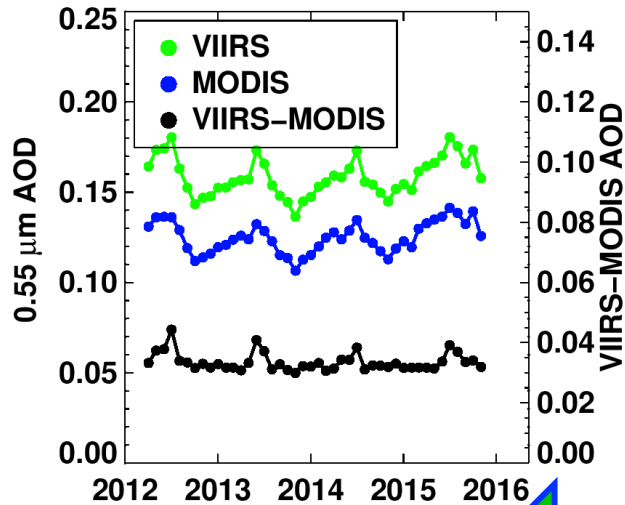
- Can we “prove” calibration differences? It’s hard!
  - Drifting orbit times →
  - Tolerance for “matches” vary
  - With of variety of time overlap, hard to find common points .



Plot drawn by Andy Sayer (GSFC), source data from Greg Quinn at SSEC Wisconsin.

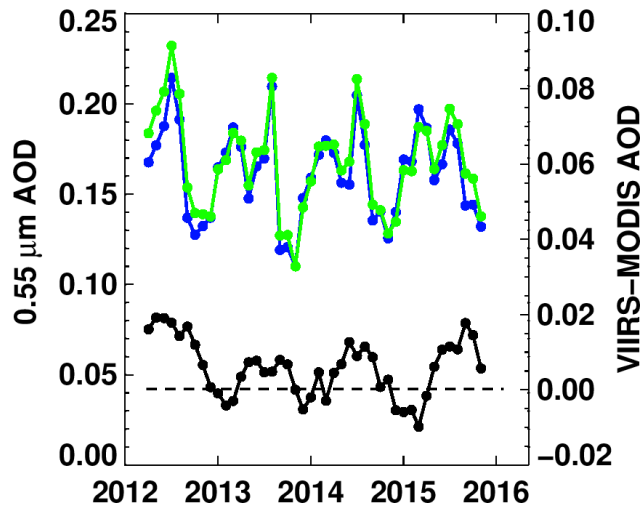
# MODIS – VIIRS overlap with the IFF

Ocean



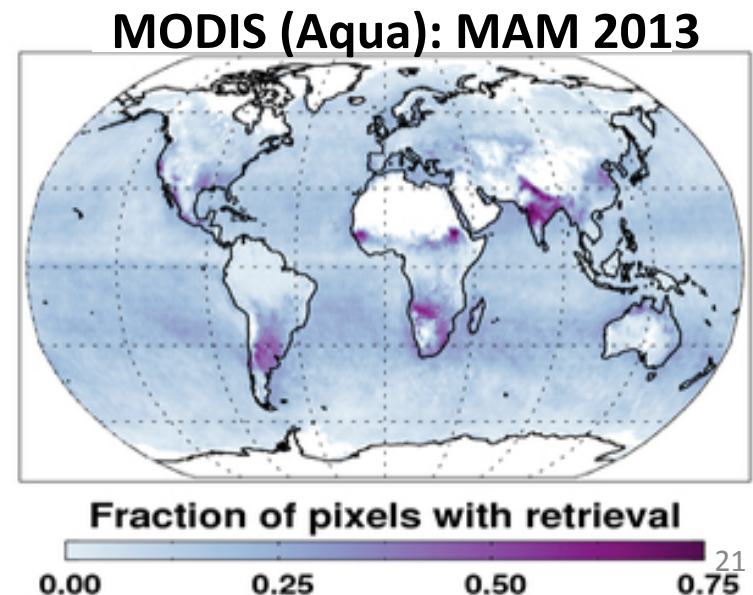
- 2012-2015.
- Ocean: Consistent offset = 0.03 (20%) with spikes in summer
- Land: Average offset is near zero, but seasonal dependence

Land



# What is good enough?

- Convergence: of gridded (Level 3 –like) data
  - For a day? A month? A season?
  - What % of grid boxes must be different by less than X?
    - in AOD?      In Angstrom Exponent?      Size parameters?
- Validation: Comparison with AERONET, etc?
- “Retrievability”: Do algorithms make same choices under same conditions?
- Other metrics?

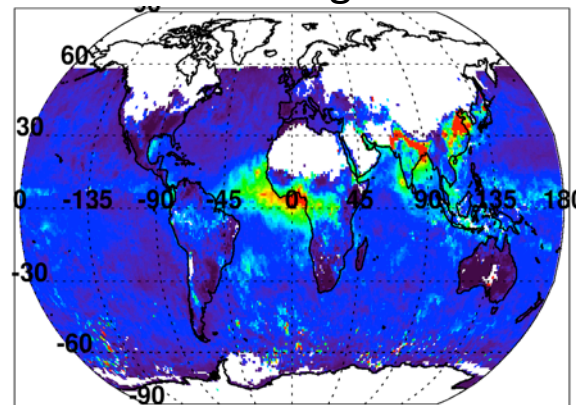




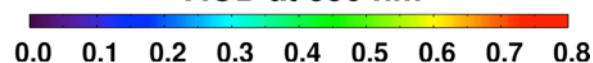
# What's still missing from IFF

- I-Bands:
  - High resolution data (375 m) could help with cloud-masking/pixel selection
- Decision on NxN pixel size:
  - MODIS scans are units of 10 detectors (e.g. 10, 20, 40)
  - VIIRS scans are units of 8 detectors (e.g. 8 or 16)
  - Current MODIS-like is 10x10, but that mixes can lines for VIIRS
  - **Doesn't make too much of a difference →**
- Land surface reflectance ratios (that exactly follow MODIS logic).
- Cloud mask (thermal-infrared tests)
- Formats, etc:
  - We are reporting products in MODIS-like formats.
  - Still awaiting science-team decision on archival formats, meta-data, etc.
- Note from C. Hsu (GSFC): Deep blue (DB) products (V1) will be delivered, independent of rest of atmospheres

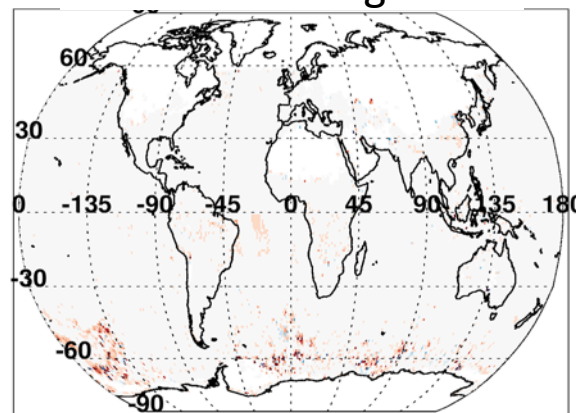
AOD using 10x10



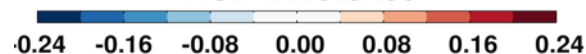
AOD at 550 nm



$\Delta$ AOD if using 8x8



AOD Difference

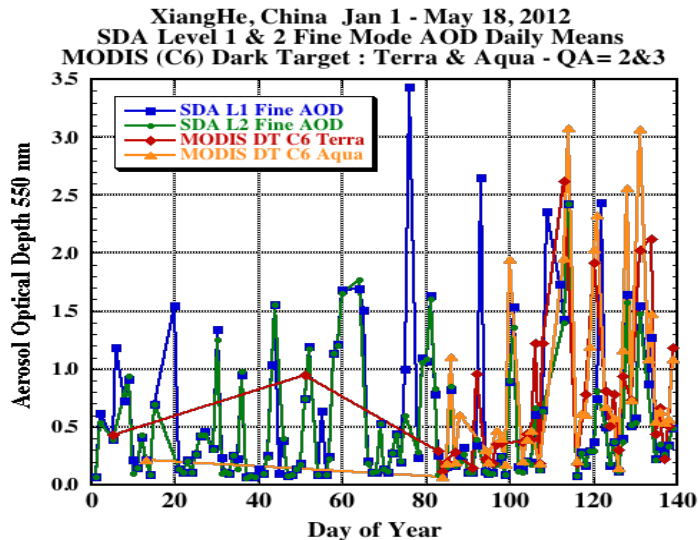


# DT retrieval: Improvements

- Improving coverage
  - Removing bias over urban areas
  - A better dust retrieval over ocean
  - Etc
- 
- Figuring out which updates will be in “forward” stream, and which can go into reprocessing.

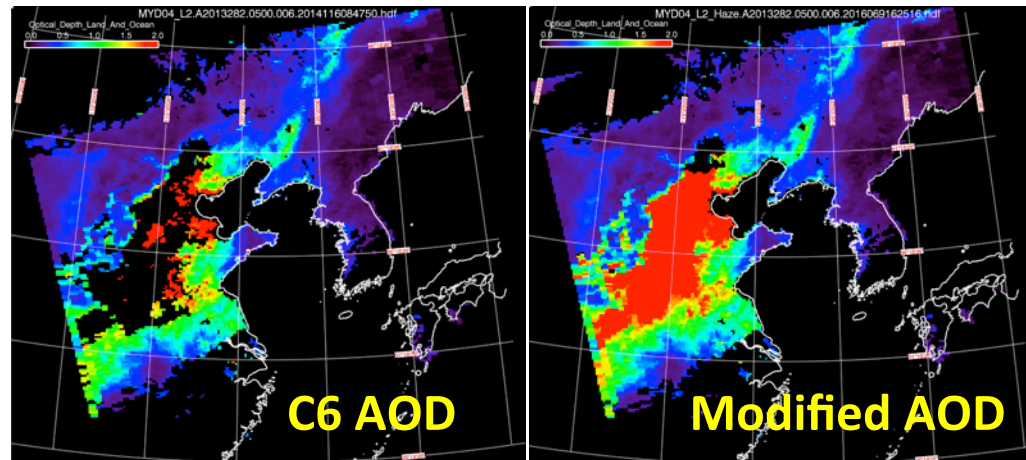
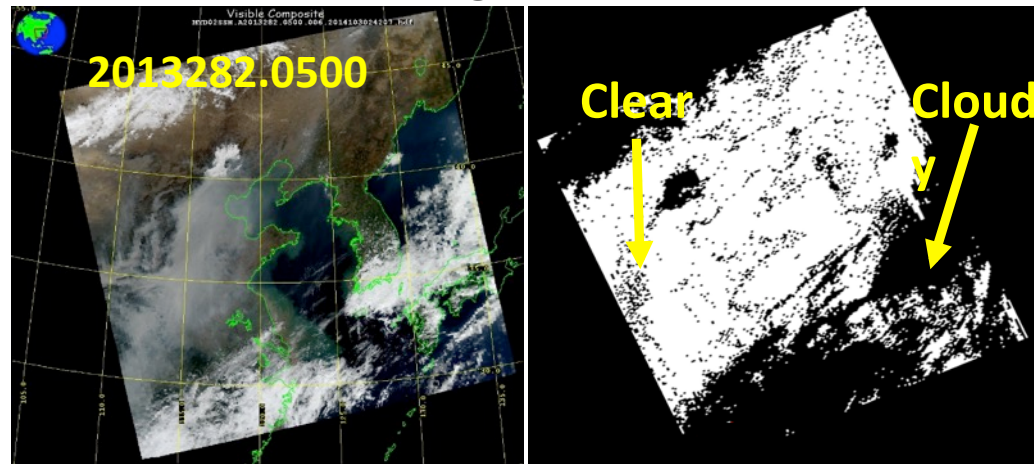
# Improving coverage

MODIS (C6) misses many AOD events during winter months (AERONET confirms not cloud)



Instead it is the “In-land water mask” that is preventing retrieval over Beijing.

Case study over Beijing area shows that our cloud mask is working

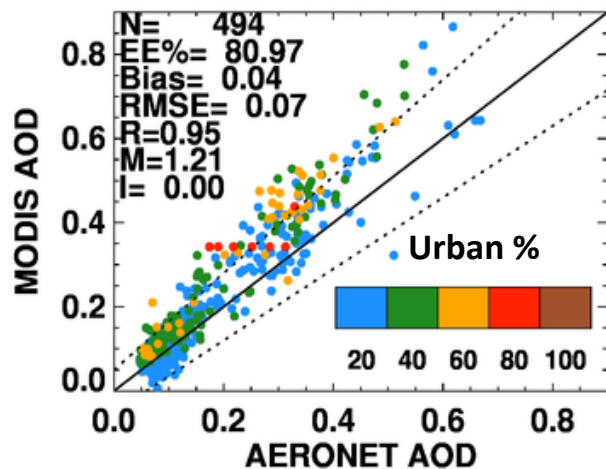


Can we relax masks, but not degrade global retrieval?

Leiku Yang and Yingxi Shi

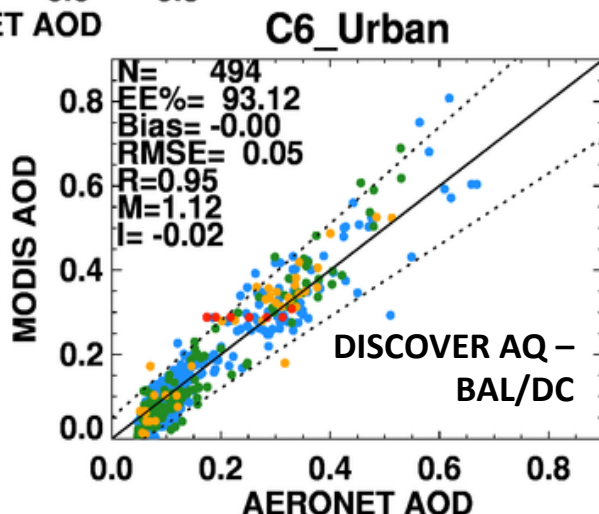
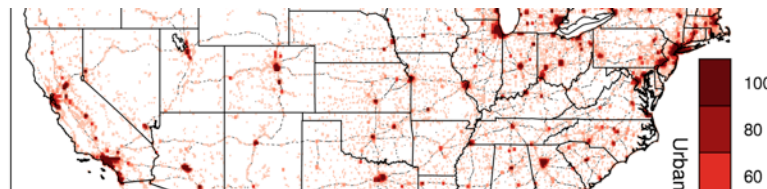
# Characterizing / correcting urban surface bias

(MDT AODs over urban surface are biased high w.r.t. AERONET)

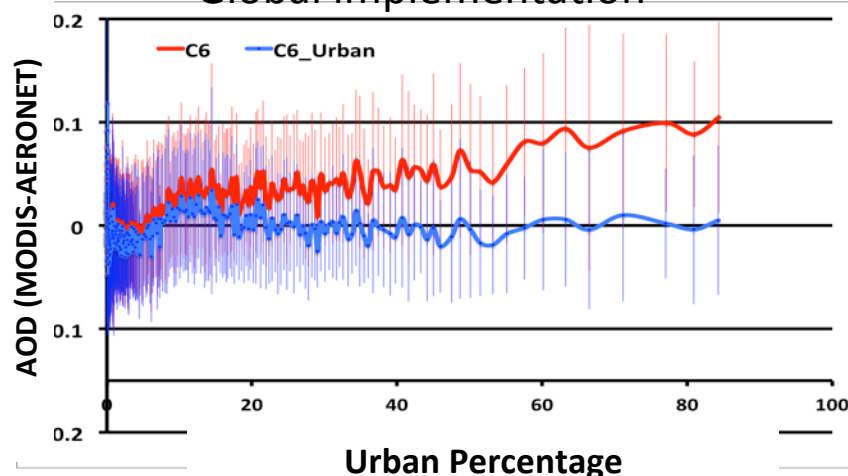


Surface scheme is revised over urban areas by integrating land cover type information in the retrieval algorithm.

Urban % in the U.S. (Cities)



Global implementation



**Revised urban algorithm works very well in the US**  
**Global implementation is challenging, but forthcoming**

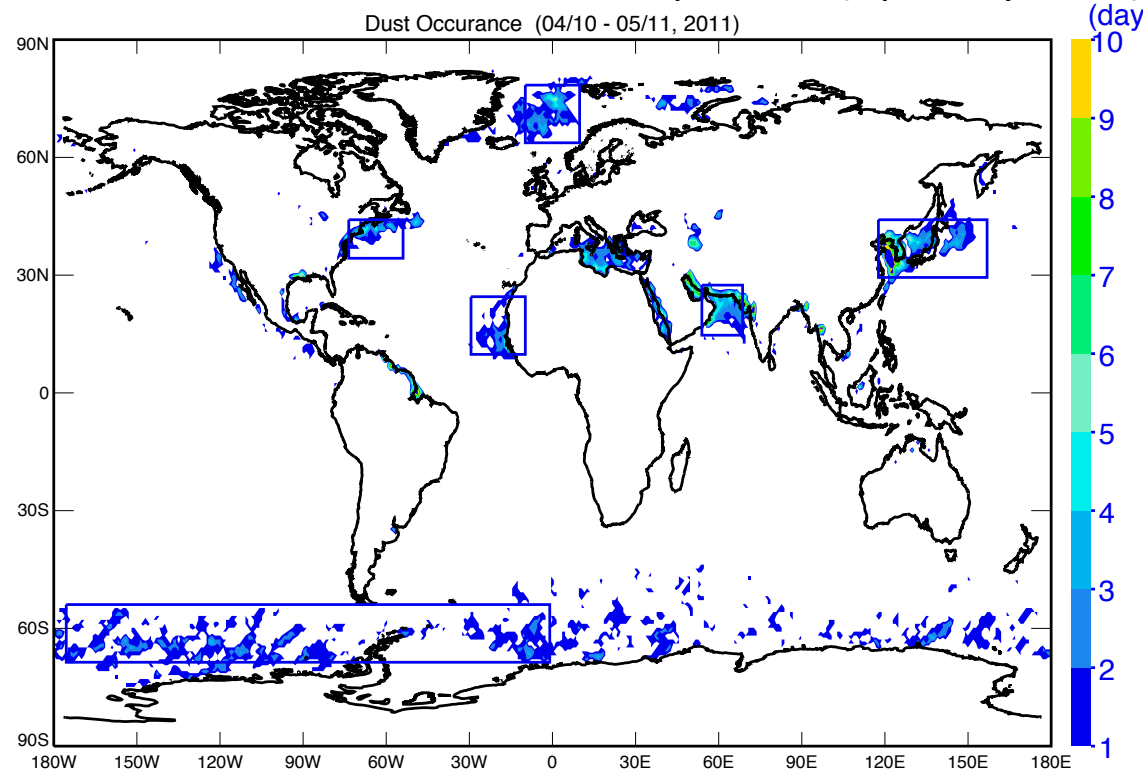
Gupta et al.,  
(in revision)



# Finding and retrieving dust

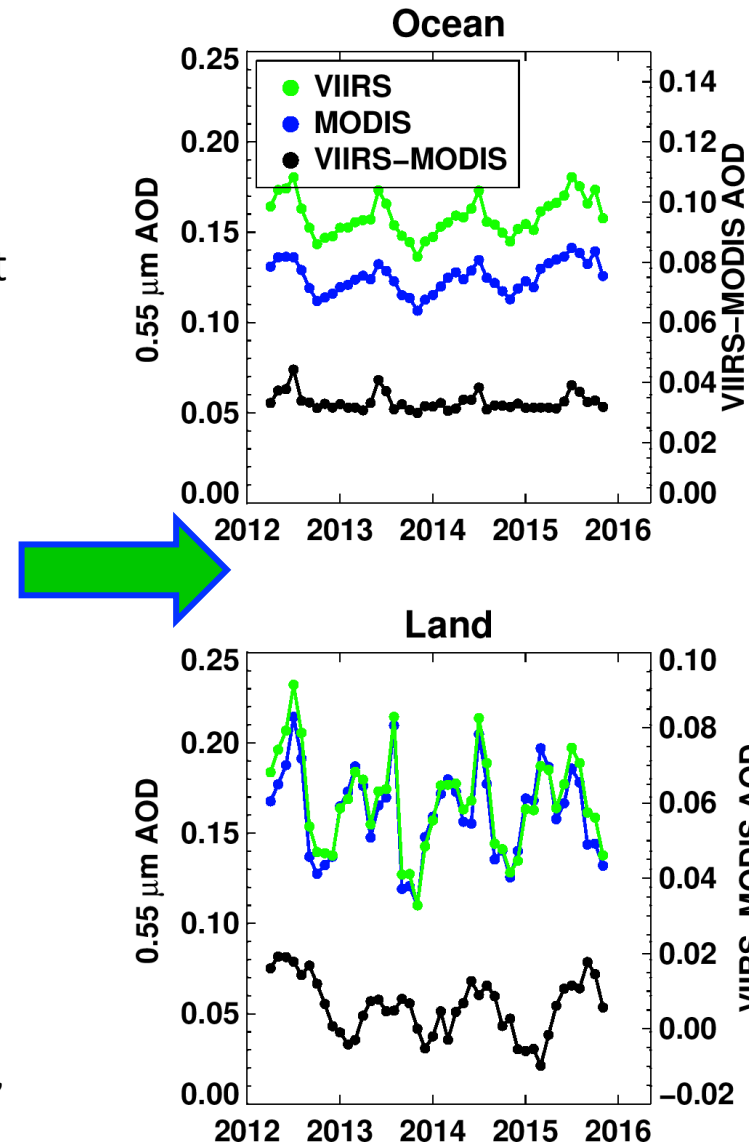
- C6 DT retrieval uses VIS-NIR-SWIR, plus TIR for cloud and snow masking.
- Over ocean, C6 DT assumes spherical coarse models
- No angular information to use non-spherical assumptions.
- But there is dust information in TIR.
- Can we detect dust, then retrieve with better models?
- → Better fine/coarse mode separation? Better spectral AOD? Better use for CERES?

Dust detection from cloud-mask product (Apr-May 2011)



# Summary (MODIS → VIIRS)

- MODIS-DT Collection 6
  - Aqua/Terra level 2, 3; entire record processed
  - “Trending” issues reduced
  - Still a 15% or 0.02 Terra vs Aqua offset.
  - Terra/Aqua convergence improved with C6+, but bias remains.
- VIIRS-DT in development
  - VIIRS is similar, yet different then MODIS
  - With 50% wider swath, VIIRS has daily coverage
  - Ensures *algorithm* consistency with MODIS DT.
  - Currently: 20% NPP vs Aqua offset over ocean.
  - Only small bias (%) over land (2012-2016)
  - Can VIIRS/MODIS create aerosol CDR?
  - Still need to define “how good is good enough?”
- DT improvements / expansion
  - Will be applied to both MODIS and VIIRS
  - DT can be applied to additional sensors (GOES-R, Himawari, PACE, etc)





# MODIS Aerosol

Dark-Target Retrieval Algorithm

OUR TEAM

PUBLICATIONS

CLIMATE & RADIATION

<http://darktarget.gsfc.nasa.gov>

Search

ALGORITHM

PRODUCTS

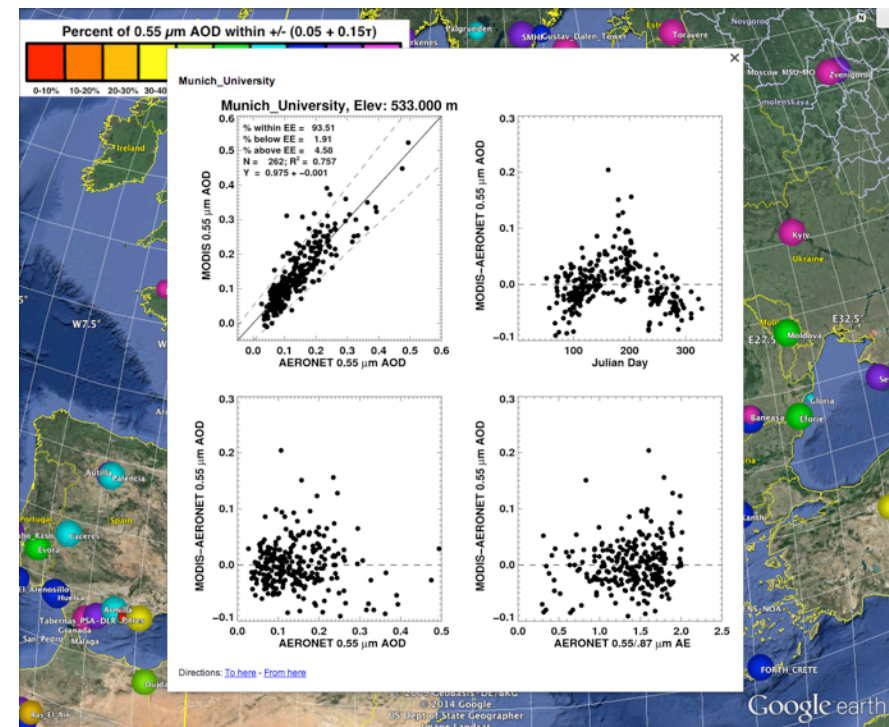
VALIDATION

REFERENCE

FAQ

LINKS

- Reference for all things “dark target”
  - The algorithms and assumptions
  - Examples
  - Validation
  - Primary publications
  - Educational material
  - FAQ
  - Links to data access
  - Considering a “forum”



THANK YOU!